FIRST RESULTS FROM THE JAMA HUMAN BODY MODEL PROJECT

Tomiji Sugimoto
Japan Automobile Manufacturers Association, Inc.
Kunio Yamazaki
Japan Automobile Research Institute
Japan

Paper Number 05-0291

ABSTRACT

The number of fatalities from automotive traffic accidents in Japan is on a downward trend. However, the number of injuries is tending to increase. Consequently, there is a need for further safety measures to reduce the number of casualties. In order to achieve progress on vehicle safety measures, it is essential to develop human body models for use as tools to quantify injury parameters. The crash test dummies and impactors in common use, however, require consideration of durability and reusability. This gives rise to structural differences from the human body, and makes it difficult to evaluate any but preexisting injury parameters. Recent years, therefore, have seen the use of simulated models of the human body generated by computer. These models take advantage of the ability to model the structure of the human body and mechanical properties in minute detail, and are applied to explain the injury mechanisms and to evaluate vehicle collision safety. Joint cooperative projects have been initiated by automobile manufacturers, related research institutes, and other such organizations, particularly in the United States and Europe, bringing advances in development of models that more closely resemble the human body. Given these circumstances, the Japan Automobile Manufacturers Association, Inc. (JAMA) has initiated activities for development and research of computer-modeled human bodies in impact biomechanics, which can analyze pedestrian and occupant injury, through a system of cooperation between industry and academia for 3 years. This report introduces the substance of those activities, their status, and some initial results.

INTRODUCTION

The number of fatalities in automotive traffic accidents has, in the past few years, shown a decreasing trend, thanks in part to automotive safety technology. On the other hand, there has been an increasing trend in the number of people injured, with more than a million people injured annually (Figure 1). Accordingly, further safety improvements are required, to reduce the number of fatalities and the number of people injured.

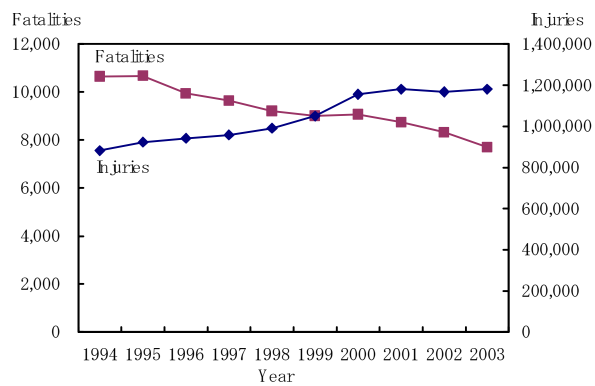


Figure 1 Trend of traffic accident fatalities and injuries in Japan

In order to make progress with safety improvements on the vehicle, research is being carried out into human body response to impact, to determine the mechanisms causing human body injury, and its limits. At the same time, in order to predict injuries to the human body, particularly during impact, and to prevent these injuries, it is necessary to estimate the effectiveness of safety devices and so on. As a tool to this end, development of a human body model is essential. For the human body model, volunteers or post-mortem human subjects (PMHS) could be considered, but generally, a human body simulation device (a crash test dummy that simulates the whole human body and impactor that simulates part of the human body) is used most frequently. However, the crash test dummy and impactor are structurally different from the human body because they must be equipped with devices to measure impact response and must be given to ease of use (durability, repetitive performance, etc.), so one concern has been the difficulty of evaluation outside of existing injury parameters.

On the other hand, in recent years there has been a focus on human body simulation models using computers, as tools that push the boundaries of existing technology, to bring new possibilities. Human body simulation models utilize features that make possible detailed modeling of both the human body structure and mechanical properties. These models can be used in analysis of injury mechanisms, and in evaluation of vehicle crash safety (Figure 2). Concerning human body simulation models, conventionally modeling was carried out for each body regions being researched, but recently, development has been carried out for full-body models such as Total Human Model for Safety (THUMS, Toyota Central R&D Labs., Inc. and Toyota Motor Corporation)[1] and H-Model (ESI)[2]. In addition, cooperative projects have begun in the USA (Human Body Modeling Partnership) and in Europe (HUMOS: Human Model for Safety)[3][4] between multiple automotive manufacturers and related research organizations, etc. These have led to the development of models that are closer to actual human bodies. This focus is on effective human body model research.

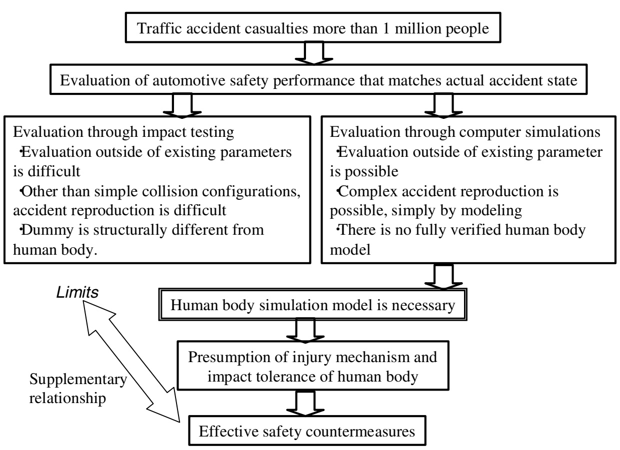


Figure 2. Necessity of human body model

Against this background, the Japan Automobile Manufacturers Association, Inc. (JAMA) has begun industry-wide activities aiming to improve research capabilities through technological interactions among automotive manufacturers and with academia, concerning human body computer model development (which has conventionally been carried out by individual automotive manufacturers) and research for this development (impact biomechanics research). This paper introduces the background of these activities, and their content.

FLOW OF AUTOMOBILE COLLISION SAFETY DEVELOPMENT OF SAFETY IMPROVEMENTS

When adopting automotive collision safety improvements (test methods and protective devices), generally research in the flow shown in Figure 3 is necessary.

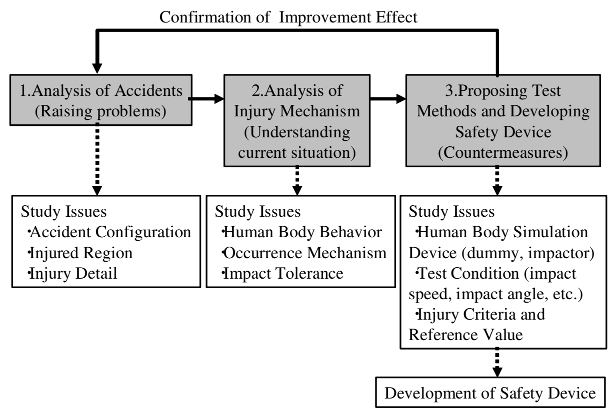


Figure 3 Flow chart of research of safety improvements

The first phase, "Analysis of Accidents", is generally understood as the phase where problems are raised. From analysis of individual accidents and the results of statistical evaluation of accidents, the problematic accident configuration (vehicle collision direction, collision speed, passenger restraint conditions, etc.), injured body region, detail of injuries, etc. are understood, and if possible, cause analysis is carried out, to predict the items coming into contact with the human body.

The next phase, "Analysis of Injury Mechanism", is the phase for understanding the phenomena themselves. In this phase, concerning the problems identified in the accident analysis phase, accident reconstruction, that is to say, vehicle and human body behavior assumptions are made, and impact conditions and impact load relating to the human body are predicted. Furthermore, from tests, etc., under impact conditions close to actual accident conditions and using the human body model, the injury occurrence mechanisms and human body impact tolerance are learned. At this time, depending on the type of human body model, it is not necessarily true that the impact conditions are equivalent to that of actual accidents without doubt. For example, in the case of actual tests using volunteers, it is necessary to estimate human body response that approximate actual accidents from data on impact conditions lower than those of actual accidents.

The phase "Proposing Test Methods and Developing Safety Devices" is the improvement phase. In this phase, the administrative side prepares test methods, and in the form of regulations or standards, uniform safety improvements is determined for the product (automobiles). On the industry side vehicle design changes are made to meet the regulations and standards, and protective devices are developed according to in-house standards, leading to the development of a safer vehicle. In any case, test methods are necessary to evaluate safety performance, and for these tests, development of dummies or impactors, setting of test conditions (test vehicle or impactor collision speed and collision angle, etc.), and the selection of physical parameters for evaluation of injury and the injury reference values (impact tolerance) are all necessary.

When the improvement phase is complete, that series of research is complete, but confirmation of improvement effectiveness is necessary as continued work. This means a return to accident analysis, and the improvement is seen to be effective, then that issue is finished and identification of other problems is carried out. However, if the initially expected effect of the improvement is not sufficiently realized, once again it becomes necessary to understand the current situation and search for further improvements.

NECESSITY FOR HUMAN BODY COMPUTER MODEL

With the human body computer model, development of bones, internal organs, and outer skin, etc., has just begun, so it is not yet perfected. However, because it has the feature of being able to make detailed models of the human body structurally and of its mechanical properties, it is expected that it will be frequently used in the collision safety improvement flow outlined above. The following shows the items in which it is thought this model can be used.

Accident Reconstruction

At present, accident reconstruction is generally through impact tests using crash test dummies and actual vehicles. However, there are the problems that it is difficult to set test conditions for accidents where there are many vehicle behaviors, and that there are limits to the areas of the crash test dummy that can be measured, and to physical properties. Therefore, these issues can be resolved by utilizing the human body computer model and the vehicle model as a set. Although there are many problems in modeling the vehicle and human body, it can reproduce human body injuries and can help analyze vehicle body and human body collision reaction forces, so it is an important tool in accident analysis.

Analysis of Injury Mechanism and Impact Resistance

Tests concerning this item generally use volunteers and PMHS. However, problems include the fact that there are limits to the physical properties that can be measured in these tests, and the fact that differences in properties due to individual physical differences (variations in shape and strength, changes in characteristics due to age, the presence of disease or illness, storage conditions, etc.) must be considered. Considering the physical properties that can be measured, the human body computer model is more effective in determining physical properties directly connected to human body tissue damage. In addition, because the model was built based on fundamental standard values, the problematic effect in the tests of individual physical differences is eliminated. On the other hand, it is possible to change, depending on the purpose of the test, the computer model's age or physique, and to analyze differences in impact resistance between the changed model and the standard model.

Crash Test Dummy and Impactor Development

When developing a crash test dummy or impactor that simulates specific parts of the human body, the problem is the biofidelity to the human body in the conditions used. In many cases, to confirm biofidelity, test data (drop test, impactor test, etc.) is used from tests implemented under simple impact conditions, to make a comparison for each human body part with volunteers or PMHS. However, if the human body computer model is used, it is possible to estimate human body response under a variety of condition, and it is possible to confirm dummy and impactor biofidelity with a wider variety of evaluation parameters.

Setting Injury Criteria

As for parameters to evaluate injury, the physical properties measured in tests using volunteers and PMHS, and the physical properties created using statistical models based on that data, are often used. However, parameters that are thought to be difficult to measure and have a low level of effect are often eliminated. With the human body computer model, it is possible to study many physical properties, and it is expected that it will be possible to select more appropriate injury evaluation parameters.

Confirming the Effectiveness of Safety Devices

When automotive manufacturers have implemented vehicle safety improvements and developed new safety devices, conventionally, evaluation is made from tests using crash test dummies and impactors simulating part of the human body. With crash test dummies, there is the problem of limits to the areas and physical properties that can be measured. With the human body computer model, many physical properties can be measured, so it is possible to evaluate the effect on the human body in many aspects.

JAPAN AUTOMOBILE MANUFACTURERS ASSOCIATION, INC. (JAMA) ACTIVITIES

In the Japanese automotive industry, development of a human body computer model has been mainly carried out by individual automotive manufacturers. Research by JAMA has been carried out together with JARI (Figure 4), and the focus has been improving parts of the existing model, based on human body data.

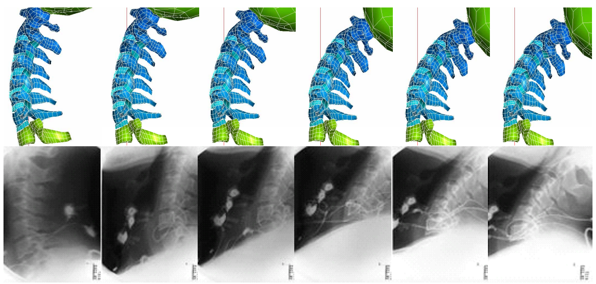


Figure 4 Simulation of cervical spine motion at rear-end impact (JAMA/JARI study)

In contrast, in the USA (Human Body Modeling Partnership) and in Europe (HUMOS), the joint research organizations (consortiums) have spanned automotive manufacturers, research organizations, and universities, etc., accelerating the development of the human body computer model.

Building on this situation, JAMA, too, has studied the promotion of a joint research organization involving automotive manufacturers, JARI, and universities, in order to strengthen human body model development.

Figure 5 is an outline of that concept. The aim is cooperation with research organizations related to the automotive industry and with universities, to implement research concerning human body characteristics and injury criteria and to build a human body computer model that can be used in automobile safety design. The plan is for an organization where research is carried out with the automotive manufacturers, JARI, and universities, etc., each having their own responsibilities for individual and joint research. Among the research items, there are some where cooperation is essential – for example, content such as human body characteristics that cannot be implemented without the cooperation of a medical university, content such as human body model mechanism and function theory construction which requires the cooperation of an engineering university, or content requiring vehicle shape data for analysis using vehicle computer models which must be carried out by automotive manufacturers, etc. In addition, research organizations, such as JARI, are necessary, to carry out engineering analysis of medical data, or to assist in the development of the human body computer model. Moreover, there is a plan to enlist the help of software manufacturers who have the know-how concerning computer models to help with some of the work, when necessary.

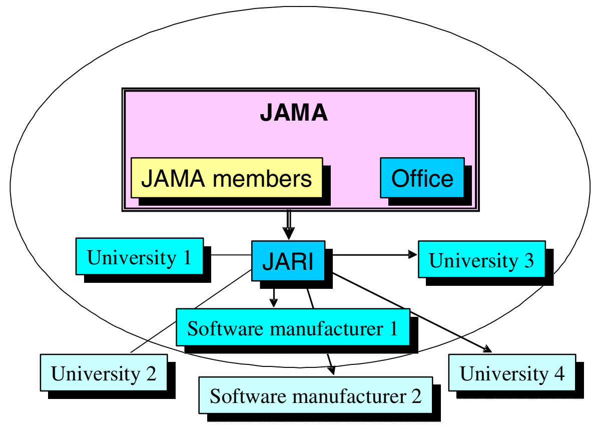
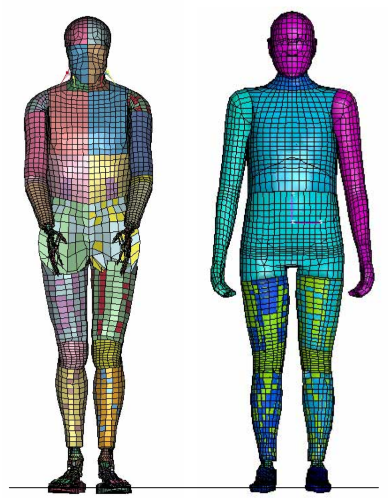


Figure 5 Outline of a joint research on human body modeling

As for the research schedule, we are starting in fiscal year 2004, and plan is to complete a human body computer model that can be used in pedestrian and passenger analysis within the next three years. In Japan, human body computer models such as THUMS and the pedestrian model based on the H-model[5] already exist (Figure 6). This year, from the point of view of utilization of existing models, a pedestrian and passenger basic model (AM50 equivalent) that integrates the existing models will be developed. In the following two years, it is planned that the model will be modified based on the latest knowledge, and posture changing technology and scaling technology will be created. Through more rapid development of a human body computer model, it will be possible to undertake early initiatives to reduce the number of casualties in automotive traffic accidents in Japan, and at the same time, Japan will play a leading role in contributing to safety improvements around the world.



(a) THUMS (b) Pedestrian model based on H-model

Figure 6 Existing human body models in Japan

The development of a human body computer model is also being tackled overseas, and JAMA would like to cooperate in those research organizations, too. However, from the point of view of taking safety improvements that match the situation in Japan, and of enhancing Japan's research base by contributing to the education of Japanese researchers, it is necessary to proceed with independent Japanese research activities.

STATUS OF DEVELOPMENT OF JAMA HUMAN BODY MODEL

JAMA has a plan to develop basic models for the pedestrian and passenger through the first half of 2005. These models will correspond to two kinds of solver (LS-DYNA and PAM-CRASH) respectively.

Development has almost been completed for the LS-DYNA version of a basic pedestrian model (Figure 7 and Figure 8). The basic pedestrian model has been developed based on both the THUMS and the pedestrian model based on the H-model. Concretely, the feature of each model was made the best use of, the THUMS was used for the upper half of the body, and the pedestrian model based on the H-model was used chiefly for the lower half of the body. The basic pedestrian model consists of 90,995 elements and 71,136 nodes, and the physique is near the AM50.

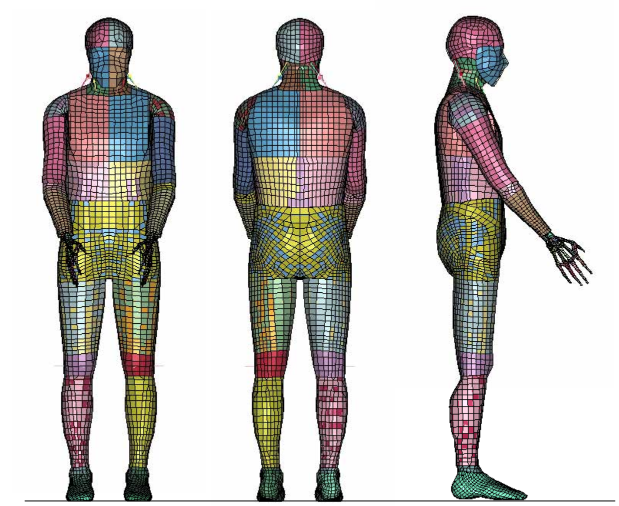


Figure 7 JAMA pedestrian model (externals)

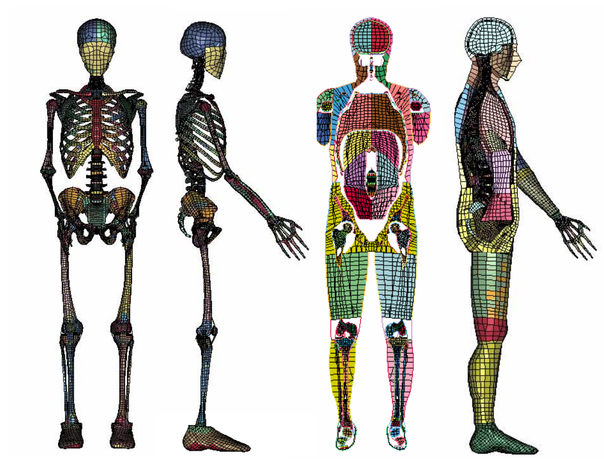


Figure 8 JAMA pedestrian model (internals)

The basic pedestrian model for PAM-CRASH will be developed by converting the model data of the LS-DYNA version. We will establish the conversion technology by accumulating experience and technology though it is difficult to convert the model for a different solver. The basic passenger model will be developed by changing the posture of the basic pedestrian model.

Basic models for the pedestrian and passenger will be improved based on the result of volunteer and PMHS tests during the next two years.

TRENDS IN OVERSEAS RESEARCH

As noted earlier, human body computer model research is being carried out in the USA and Europe, involving joint research organizations. The following is a brief explanation of their recent activities and situation.

In the USA, the Human Body Modeling Partnership began, with automotive manufacturers taking the initiative. The emphasis is on consortium style activities involving automotive manufacturers and research organizations, etc. including those outside the US. The aims are to modify injury evaluation parameters and criteria through the development of a human body computer model, and to expand accident reproduction research. In addition, through consortium type activities, it is expected that redundancy or incompatibility will be eliminated, development of the model will be accelerated, and costs will be reduced. Although full-scale activities will begin next year, in the first five years adult models of three physiques for both men and women (small frame, standard and large frame) will be created.

In contrast, in Europe, the consortium called HUMOS is already active. Participating members include five European automotive manufacturers, three software manufacturers, and seven research organizations or universities. Their goals and aims are basically the same as the Human Body Modeling Partnership noted above. Their research schedule is divided into phase 1 (HUMOS 1) and phase 2 (HUMOS 2). In phase 1, they were developing a passenger model of a European adult male 50th percentile size. This activity is complete. At present, phase 2 activities are being carried out, and with a target of the autumn of 2005, they are hurrying to build a model lineup of three models – a 5th percentile female, a 50th percentile male, and a 95th percentile male.

THE DIRECTIONS OF HUMAN BODY COMPUTER MODELS

Finally, the following is a discussion of the future directions for the human body computer model.

Detailed Modeling

The first human body computer models were based on multi-body dynamics. At that time, the aim was mainly analysis of the motion of human bodies during collisions. Later, for injury evaluation, it became necessary to have detailed modeling of each human body area, and so human body computer models were most often based on the finite element method (FEM). Models according to FEM were, at first, most often detailed models of the skeleton only. However, at present, there are also examples of modeling of internal organs or blood vessels. In the future, other human body systems (muscles, nerves, etc.) will also be modeled in detail.

Diversification of Injury Detail

In recent automotive accidents in Japan, there has been a reduction in the number of fatalities, with 8,000 people in 2003. In contrast, the number of people injured exceeded one million people in 1999, and has continued to grow since then with almost 1.2 million people the past few years.

Knowing this, vehicle safety improvements that have conventionally placed emphasis on reducing fatalities, have recently also begun to tackle reducing the number of people injured. For example, in the case of Japan, in safety standards that have existed for some time, the evaluation index was based on injury criteria in areas of the human body that cause death. However, in automotive assessment that aims at technology innovations that give better safety performance, the evaluation area extends into areas of the human body that have very little chance of causing death.

Accordingly, it seems that in the future research will focus on things other than large injuries causing grave damage such as death or severe injury. This means that detailed modeling of areas that have been omitted in the past will become important.

Improvements for the Elderly

In Japan, the number of deaths of elderly people is fewer over the past few years, but looked at as a portion of the whole, it is a rising trend. In 2003, there were 3,109 fatalities (of people 65 years old or older), and this accounted for approximately 40% of the total fatalities, including juveniles. In addition, in the case of the elderly in comparison with young people, it was learned that their rate of fatality is high, and when they are passengers in the vehicle cabin, they are more easily injured in the chest, etc. However there is not sufficient understanding of the causes of these phenomena. In Japan, the population of elderly people is rising dramatically, and in the future, there will even greater demand for research into collision safety for the elderly.

Enhancement of Surrounding Technology

With the latest human body computer model, each area of the human body is modeled in some detail, and even joint modeling, which traditionally had mathematical joint mechanisms, is now closer to actual human beings. Through this type of detailed modeling, position changing, which wasn't a problem with the first human body computer models, has become more difficult with recent models. Position changing technology is becoming increasingly important in actual analysis.

Furthermore, when evaluating vehicle safety, it is becoming necessary to ensure safety performance for passengers of a variety of physical types, other than the standard physique. When analyzing accident reproductions, too, there is a requirement for technology that can freely change the physical type. Therefore, in the future, body frame scaling technology must be developed.

CONCLUSIONS

In automotive safety performance research, vehicle and part impact tests are carried out using crash test dummies and impactors that simulate areas of the human body, and evaluations made of the safety performance, as to whether or not it meets human impact tolerance (injury criteria) as determined from tests using volunteers and PMHS. Impact biomechanics research, which is the foundation in determining these injury criteria, has mainly been implemented in Europe and the USA, with little contribution from Japan. However, in the future through the development of human body models, at the same time as comprehensively and systematically incorporating impact biomechanics research, a Japanese research system will be enhanced following the consortium organization system, raising the level of Japan's contribution, and creating an environment where comprehensive injury reduction improvements that match the Japanese situation will be tackled.

REFERENCES

[1] Instruction Summary of Total Human Model for Safety (THUMS), Toyota Central R&D Labs, Inc.

[2] H-Model Overview Description, ESI Group

[3] Praxl, N. et al.: Simulation of Occupant Kinematics in Vehicle Rollover - Dummy Model Versus Human Model, Proceedings 18th International Technical Conference on the Enhanced Safety Vehicle, Paper Number 202

[4] Robin, S.: HUMOS: Human Model for Safety – A Joint Effort towards the Development of Refined Human-like Car Occupant Models, Proceedings 17th International Technical Conference on the Enhanced Safety Vehicle, Paper Number 297

[5] Dokko, Y.: Validation of the Human Head FE Model Against Pedestrian Accident and its Tentative Application to the Examination of the Existing Tolerance Curve, Proceedings 18th International Technical Conference on the Enhanced Safety Vehicle, Paper Number 322

[6] Nishimoto, T.: The Current Situation surrounding Impact Biomechanics Research and JARI Initiatives, The Japan Society of Mechanical Engineers, M&M 2003 Materials and Mechanics Division Conference, OS-8

[7] Ono, K.: Biomechanics for Occupant Protection Research, JARI Research Journal, Vol.26, No.3, pp.119-125